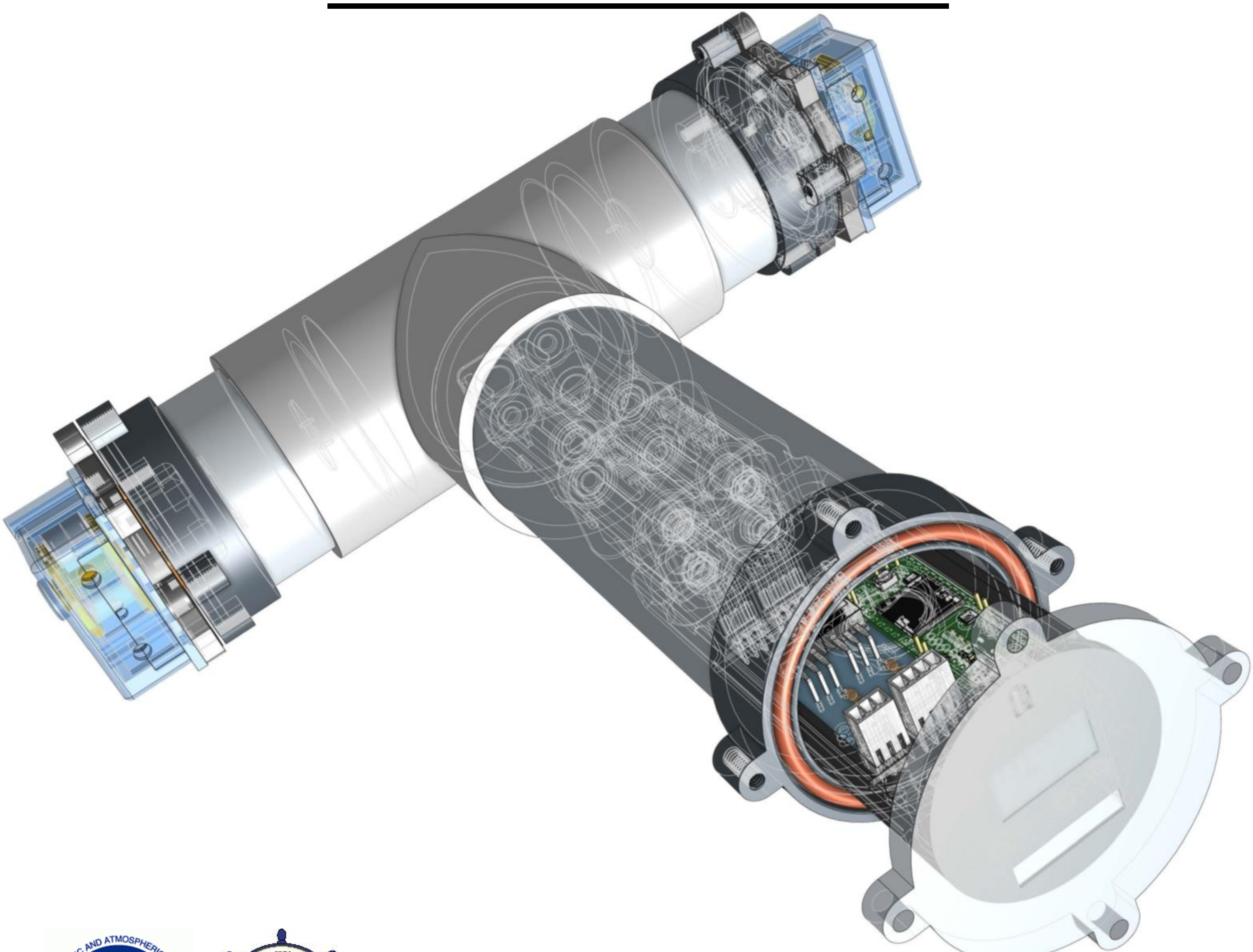
Sub-surface Automated Sampler (SAS)

Build Manual



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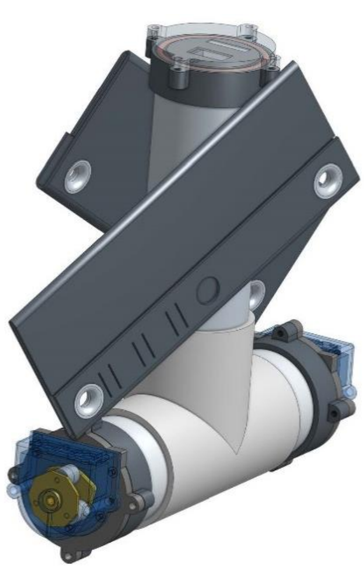
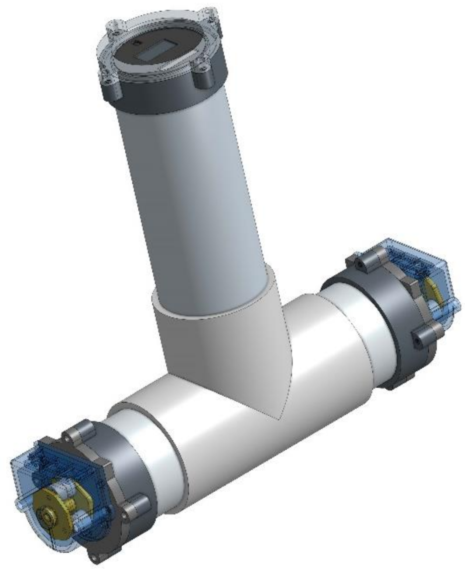




Written By Nathan Formel

October 2018

-Updated August 2019-

This sub-surface automated dual water sampler (SAS) was designed, created, and tested by researchers at NOAA and the University of Miami to enable researchers to study water chemistry on shallow reef habitats and further understanding of the conditions present in coral reef ecosystems. The project was intended to enable not just research institutions, but other interested parties as well by acting as a low cost alternative to other existing automated water samplers. The open-source design will continue to be developed and improved on by NOAA and University of Miami researchers, as well as the science community at large. This build manual is meant to serve as an exhaustive resource for any group to build and troubleshoot their own water samplers. Further resources and future updates to the SAS design are available on the NOAA website (http://www.coral.noaa.gov/accrete/SAS)

Table of Contents

1. Resources and Materials Needed

The SAS is meant to embrace simplicity in its design, so no extensive background in circuitry or engineering is required to build your own, however there are some tutorials that might prove useful in introducing skills to novice builders such as soldering (https://learn.sparkfun.com/tutorials/how-to-solder-through-hole-soldering), 3D printing (https://formlabs.com/blog/ultimate-guide-to-stereolithography-sla-3d-printing/), laser cutting (https://www.instructables.com/id/Laser-Cutting-Basics/), or circuit board milling ((http://blog.bantamtools.com/how-to-make-pcb-using-desktop-cnc-mill). If a builder intends to edit parts of the design, an introduction into a CAD program (https://learn.onshape.com/) and some background on Arduino-based circuits and coding could be useful as well (https://www.arduino.cc/en/Guide/Introduction).

The grant that funded the SAS project also funded construction of a workspace at NOAA's Atlantic Oceanographic and Meteorological Lab for prototyping this and future marine research equipment. This Advanced Manufacturing and Design Lab (AMDL) includes multiple stereolithography (SLA) 3D printers, an automated circuit board milling machine, a laser cutter, and a pressure chamber, all to allow rapid prototyping in-house. These tools can get expensive and would be cost-prohibitive to most groups, however, there are alternatives to making all the components yourself, with many online businesses available to order parts from using the SAS design files. To make sure this build process is functional for both large and small budgets this manual will begin with a list of all the components that were made in-house and alternatives to personally making these parts, followed by a list of all parts required. At the time this manual was written the cost for making one SAS, production equipment notwithstanding, is $213.34.

3D Printed Components

All of the 3D printed parts that were made in-house were first designed in OnShape's cloud-based CAD software. It's worth noting that OnShape offers a free account for students and educational institutes (https://www.onshape.com/products/education) and has excellent customer service, online tutorials, and webinars to reduce the learning curve for a CAD program. The parts required for the SAS were printed on a Formlabs Form2 SLA printer. The need for waterproof components required that the SLA method be used over the more traditional fused deposition modeling. At the time this manual was written the cost for a Form2 kit is $3,350 and a 1 liter cartridge of the standard resin used for this project costs $149. For builders new to 3D printing, Formlabs also has excellent online resources and tutorials for understanding SLA printing (https://formlabs.com/resources/). If access to a SLA printer or the purchase of one is unrealistic, parts can be ordered online through sites like Xometry.com or Protolabs.com, or through the OnShape compatible company i.materialise (https://i.materialise.com/en). The cost of printing the parts necessary for one SAS in-house, as figured by the price of the resin required, and not including the cost of setting up a 3D printing lab, is $37.01. Those components are listed below and each part has a STL file for download on the SAS website Build A SAS page (http://www.coral.noaa.gov/accrete/SAS) that can be used to print identical parts or be sent to a manufacturer for production.

3D Printed Components List

- *Part name and description (Quantity Required)*
- End Cap (3)
- Face Mount (2)
- Motor Mount Adapter (2)
- Internal Frame (1)
- 4mm pump roller carriage (2)

Laser Cut Components

The one laser cut part for the SAS is the quarter inch clear acrylic face plate. The laser used at OCED is a Boss LS-2436 150W. The cost of this laser at the time this manual was written is $13,000.00, as such, if this isn't a tool available to the builder, a CNC machine could also be used to cut the part from stock acrylic, a local Makerspace may be able to cut the part, or it can be ordered from a company online like Pololu.com (https://www.pololu.com/product/749). The vector file for cutting the face plate or ordering an identical part can be downloaded from the Laser Cutting File link on the SAS website (http://www.coral.noaa.gov/accrete/SAS). To create an identical faceplate the part should be cut or milled out of 1/4 inch clear acrylic, the blue lines in the vector file should be full cuts, and the red lines should be engraved to 1/64 inch deep. The cost of the material for the face plate is $0.50.

Laser Cut Components List

- *Part name and description (Quantity Required)*
- Acrylic Face Plate (1*) **Testing the sampler housing for leaks will require 3 acrylic face plates*

Milled Circuit Board

The double-sided circuit board in this design is where the majority of the electronics are mounted. It can be milled on a desktop milling machine, like an Othermill, using the Gerber files that can be downloaded from the Circuit Board Design files link on the SAS website (http://www.coral.noaa.gov/accrete/SAS), or the files can be used to order the board online. The benefit of ordering the part rather than milling it in-house is that it's typically more cost-effective, the circuit board comes out cleaner, and the components can be ordered soldered in place to save time. One option for ordering the circuit board online is a company called Seeed studio (https://www.seeedstudio.com/fusion_pcb.html). Using the files downloaded for the circuit board design from the SAS website and the following board specifications, the circuit board alone, or the assembled circuit board can be ordered from Seeed Studio.

Seeed Studio Board Specifications:
Base Material: FR-4 TG130
No. of Layers: 2 layers
PCB Dimensions: 43.4mm x 61.6mm
No. of Different Designs: 1
PCB Thickness: 1.6mm
PCB Color: Black
Surface Finish: HASL

Minimum Solder Mask Dam: 0.4mm↑
Copper Weight: 1oz.
Minimum Drill Hole Size: 0.3mm
Trace Width / Spacing: 6/6 mil
Blind or Buried Vias: No
Plated Half-holes / Castellated Holes: No
Impedance Control: No

To order the circuit board assembled the BOM (Bill of Materials) and the Assembly Drawing files from the SAS website need to be uploaded on the Seeed website as well. The circuit board will be received with all the necessary components installed **except** for the Teensy 3.5 microcontroller, the temperature breakout board, and the RTC coin cell battery holder. These parts are not included on the Seeed Studio order to avoid complicating the process and to keep costs down. To have the Teensy 3.5 installed it would need to be sourced separately and sent in advance to Seeed Studio for installation, and the cost per unit goes up significantly if more than one side of the circuit board is being soldered. ***If the board is ordered from Seeed Studio assembled, then the parts listed on the BOM as well as the blank circuit board are not needed in the list of parts to order below.***

Parts to Order
The majority of the parts for building the SAS housing can be purchased at a hardware store while most of the electronic components are easily ordered online. The total cost of purchased parts for one SAS is about $175. Something worth noting is that sourcing parts for the SAS project was limited to our approved vendors, which excluded online resale shops and online marketplaces (e.g. eBay.com, Amazon.com). **Having access to these types of stores could considerably reduce the cost of many of the SAS components.** Below is a comprehensive list of all the parts not made in-house that are required to build a SAS. Where necessary, extra information is included to highlight the necessary part specifications since many different sources for purchasing these parts online or in stores exist.

Parts to Order List

- *Part name and description (Quantity Required)*

Hardware

- #6-32 x 1" Faceplate screws (12)
- #6-32 Lock nuts for faceplates (12)
- #6-32 3/16 Reed switch mount screws (2)
- #6-32 x 1 1/8" Pump mount screws (2)
- #4-40 x 1/2" Motor mount screws (4)
- #2-56 x 3/4 Circuit box screw (1)
- #2-56 x 1/8 OLED screws (2)
- #2-56 x 1/2" 9V snaps mount screws (2)
- #2-56 9V snaps nuts (2)
- 6.75” length of 2” wide Schedule 40 PVC pipe (1)
- 2.25” length of 2” wide Schedule 40 PVC pipe (2)
- 2" wide Schedule 40 PVC Tee Fitting (1)
- 11” long cable tie (3)
- Stainless steel ¼” diameter carabiner (4)

Specialty Items

- Endcap O-ring (-227 cs 1/8" S70) (3)
- Motor shaft O-ring (-007 Buna-N 70 Durometer X-Ring) (2)
- 16.5” x 8.75” piece of 2mm Neoprene fabric (2)
- Stainless steel fabric grommets (8)
- 3.5” length of Tygon® A-60-G Tubing (3/16" ID x 5/16" OD x 1/16"Wall) (2)
- 1L Tedlar Bags (w/ grommet) (P/N: GD0707-7000) (2)
- Williamson Peristaltic pump - 200 series, No Motor, Unsealed, 3 Rollers, 5.0mm Silicone Tubing (2)
- 12V 170RPM Econ Metal Gearmotor (P/N: 638354) (2)
- Teensy USB Development Board (Version 3.5) (1)
- Eagle Plastics 4AA Battery Pack with Snap Terminals (P/N: 12BH341-GR) (2)

Electronics

- 15” length of 22 AWG Red Wire (2)
- 15” length of 22 AWG Black Wire (2)
- One 4” length of red 26 AWG wire (1)
- Seven 4” lengths of different color 26 AWG wire (1)
- 0.5” length of 1/16” ID Heat shrink tubing for power connections (3)
- 0.5” length of 1/8” ID Heat shrink tubing for motor connections (4)
- IR Sensor ((P/N: TSOP38238) (1)
- OLED (0.96 inch I2C Serial 128X64 SSD1306 LCD Screen, GND VCC SCL SDA) (1)
- Reed Switch (100V DC, Dimensions: 27 x 14 x 8mm) (1)
- Temperature breakout board (MCP9808 TEMP I2C BREAKOUT BRD) (1)
- RTC Coin Battery Holder (20mm between pins) (1)
- N-Channel MOSFET (IRLB8721 HEXFET® Power) (2)
- 1N4001 Diode (2)
- 1K OHM 1/4W 1% AXIAL Resistor (2)
- 100K OHM 1/4W 1% AXIAL Resistor (1)
- 390K OHM 1/4W 1% AXIAL Resistor (1)
- 3.3K OHM 1/4W 5% AXIAL Resistor (1)
- KK Connectors - 2 holes female (3)
- KK Connectors - 2 holes male (3)
- KK Connectors - 3 holes female (2)
- KK Connectors - 3 holes male (2)
- KK Connectors - 4 holes female (1)
- KK Connectors - 4 holes male (1)
- KK Crimp Terminal (16)
- Header Pins - 6 Position (3)
- Dupont crimp connector housing – 3 hole female (1)
- Dupont crimp connector housing – 4 hole female (1)
- Dupont female crimp pins (7)
- Spool of Solder (Lead-free) (1)
- Namebrand AA Rechargeable NiMH Batteries (8)

- Double-sided blank circuit board (1)
- Dual 9V Battery Strap (Series)(P/N: 229) (1)
- IR Remote (38KHz NEC code output, 940nm IR LED) (1)
- MicroSD Card (Class 4 or higher)(1)

Adhesives

- Two-Part Marine Epoxy (1)
- PVC Regular Clear Cement & Primer (1)
- Acrylic solvent cement (1)
- Silicone lubricant (1)

Tools Needed

- Soldering iron
- Flush wire cutters
- Crimping pliers
- Wire strippers (22-26AWG)
- Cutting Punch for grommet holes
- Installation Punch for grommets
- Phillips-head screwdriver
- MicroSD card adapter
- USB Cable with 5-pin Micro-B Plug

2. Building the Waterproof Housing

i. Prepare parts

Print and cut all parts listed in the 3D Printed Components and Laser Cut Components lists in the Materials Needed section.

Take the three end caps and use sand paper to sand away any tabs and roughen the surface on the inner walls of the cap (See Image 1). All of the surfaces to be attached with epoxy or other adhesives will be sanded first to improve adhesion.

Cut the 2” PVC Schedule 40 piping into one 6.75” long section and two 2.25” long sections. Sand the first inch or two of the outer edge of each piece of PVC as well as the lip of the piping to help the adhesives bind (See Image 2). Also sand the inner edges of the PVC Tee fitting. Use a cloth or paper towel moistened with isopropanol to clean off all sanded areas on the PVC and 3D printed components and allow to dry (water can be used instead of isopropanol but more care will be needed to ensure the sanded areas are clean). Check the depth of the PVC piping on the PVC fitting and the 3D printed caps (it should be about 1.4” on the PVC Tee and 0.6” on the cap) and put a strip of tape on the sections of PVC to keep the edges of the glued and epoxied areas clean.

Image 1: The two arrows point to the two surfaces that need sanding prior to applying epoxy.

ii. Apply adhesive

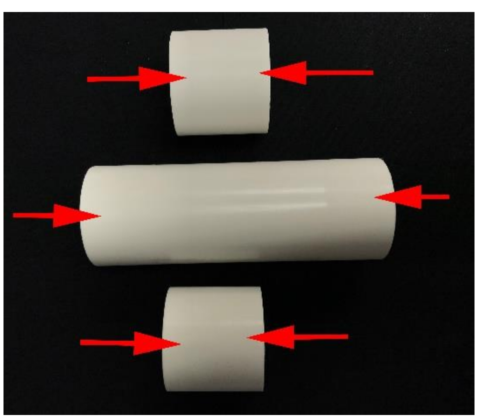


Image 2: The red arrows indicate the areas to sand on the PVC pieces.

Apply PVC primer to the insides of the two opposite PVC Tee fitting holes and to one side of each of the two inch long PVC sections. Apply PVC cement to the newly primed areas on the PVC Tee fitting and the two inch PVC sections and push the PVC parts into the fitting until fully inserted giving a quarter twist. Stand up the newly cemented PVC fitting and weight the top section to add pressure to the parts, clean up any excess PVC cement and remove tape, and then leave to cure for at least 15 minutes. Next add PVC primer to the inside surface of the middle PVC Tee fitting and one side of the longer PVC section (See Image 3). Add PVC cement to the same surfaces and then push the PVC section into the fitting until fully inserted giving a quarter twist. Stand up the PVC Tee and weight the top section to add pressure to the parts, clean up any excess PVC cement and remove tape, and then leave to cure for at least 2 hours for a full cure.

Image 3: Cementing the PVC parts together.

The 3D endcaps will be epoxied onto the free ends of the PVC sections using a two-part epoxy. Use caution to not get epoxy on the O-ring face of the endcap as that could create problems making the housing watertight later on. Ensure proper mixing of the two-part epoxy by using a mixing tip (See Image 4) or stirring the two-parts together in a cup or on a tray until a uniform color, then add epoxy to the corner of the entire wall of the inside of one of the endcaps and along the lip and upper edge of one of the short PVC pieces (See Image 5). Smooth out the epoxy to ensure consistent coverage across the inner walls of the endcap and the outside end of the PVC pipe. Push the two pieces together until the PVC is fully inserted giving a quarter twist to remove any gaps in the coverage of the epoxy. Make sure the tabs of the endcap are oriented at 45 degree angle from the long PVC section so that the body of the housing doesn't get in the way of accessing the tabs (See Image 6). Be careful not to let the endcap shift in position or slide off the PVC section. Clean off any excess epoxy from both the outside and the inside edges of the endcap and then flip the housing over. Use the same method to epoxy an endcap to the opposite free PVC section. With both endcaps on, stand the PVC frame up with one endcap on a flat surface and the other pointing up. Again, clean off any excess epoxy. Place a weight on the raised endcap to apply pressure to the PVC/endcap joins (See Image 7), remove the tape, and leave for 18-24 hours for a full cure.

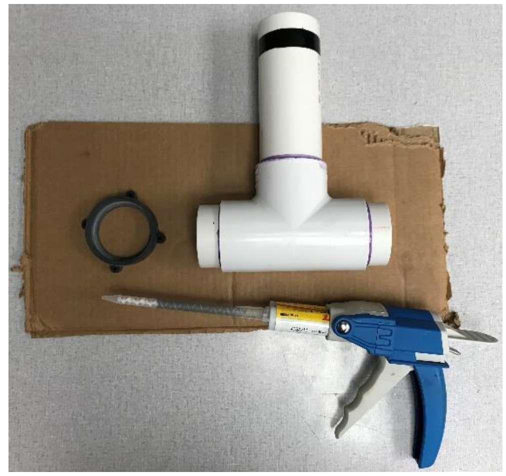


Image 4: Two-part epoxy with mixing tip to ensure proper mixing prior to applying epoxy to attach endcaps to PVC housing.

Image 5: Areas to apply epoxy when attaching endcap.

Image 6: The tabs of the end caps at a 45° angle to the main housing body.

After the epoxy on the first two endcaps has cured use the same method described above to epoxy the third endcap onto the free end of the long PVC section. Clean off any excess epoxy and then stand the PVC frame on the new endcap, weight the top to apply pressure, then remove the tape. Leave for 18-24 hours for a full cure.

Image 7: Weight the endcaps in position during curing.

iv. Testing the housing for leaks

Once the adhesives are all fully cured the housing can be checked for leaks using three of the acrylic faceplates. Install four #6-32 x 1 inch long stainless steel screws into each of the endcaps in the threaded tabs. Lightly lubricate the three -227 O-rings with a silicone lubricant and install one into each of the three endcap O-ring grooves. Remove the protective plastic layer from the unscored side of three of the laser cut acrylic face plates. Place an acrylic face plate onto the mounting screws on each endcap, plastic layer facing out, and secure using four #6-32 lock nuts. **Please note, to create a watertight seal the nuts only need to be hand-tight and the O-ring will visibly deform and seal against the acrylic. Overtightening the nuts can break the 3D printed endcap, or the acrylic face plate, or both.**

Place the now sealed housing into a bucket of water and hold beneath the surface or weight it down. Look for any streams of bubbles escaping the housing as an indicator that water is getting in and the housing is leaking. When you remove the housing look for any signs of water intrusion inside the housing. If there is a leak, determine where it is located. Leaks on the epoxy may be repairable by adding a line of epoxy to the edge of the endcap/PVC connection. Leaks at the O-ring/acrylic seal may be evidence of a damaged O-ring or dust, hair, or another particle on the O-ring or in the O-ring groove preventing a proper seal.

3. Setting up the Motors and Motor Face Mounts:

i. Attaching the adapter:

To mount the 12V 170RPM Econ Metal Gearmotor in the sampler it needs to be attached to the 3D printed motor mount adapter. Use sandpaper to roughen the top of the body of the motor (See Image 8A) and the inside surface of the adapter. Use a cloth or paper towel dipped in isopropanol to clean off the sanded surfaces of the motor and the adapter and let dry. Put a bead of two-part epoxy around the top of the body of the motor and around the inside of the adapter. Push the motor into the adapter giving a half turn and stop so that the flat end of the adapter is flush with the motor face (See Image 8B). Clean off any epoxy that has made it onto the face of the motor, keep the motor and adapter face flush, and let the epoxy cure for 18-24 hours before using the motor.

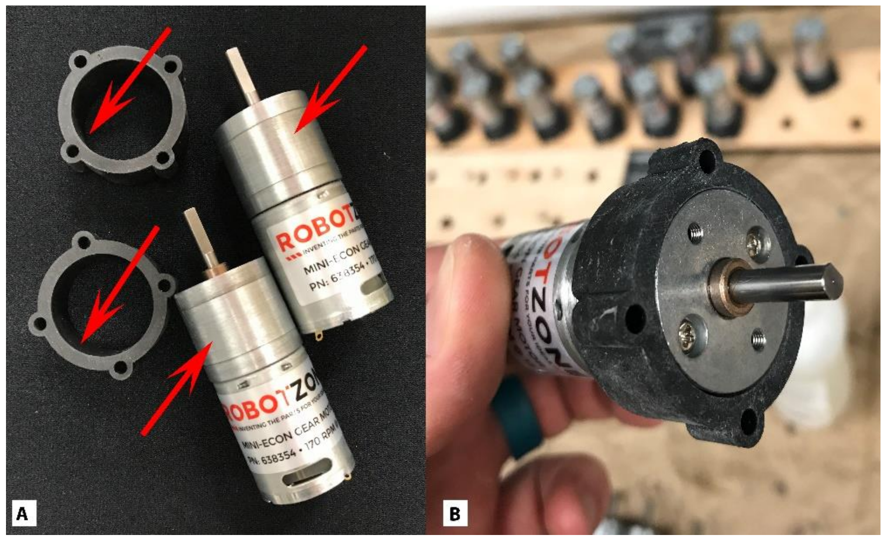


Image 8: (A) Areas to sand on the motors and adapters. (B) The motor and adapter faces must be flush when epoxied.

ii. Wiring the motors:

Remove the last 1/2 inch of the insulated sleeve from one end of a 15” length of each red and black 22 AWG wire and twist onto the positive (red) and negative terminal on the back of the motor. Solder the wires onto the terminals and cover with a 1/2 inch of heat shrink tubing for added stability. On the opposite end of each 15” wire remove the last 1/8 inch of the insulated sleeve and connect a KK crimp terminal. Install the crimped wire into a 2-hole female KK connector with the red wire on the left side (See Image 9). Repeat for the second motor.

Image 9: Connection of the motor wires to the female KK connector.

iii. Mounting the motor:

The motor face mount needs to be sanded smooth before being used. Starting on the outside face of the motor face mount (the side without the X-ring groove, See Image 10A), use a rough sandpaper to sand the surface until it appears uniform and smooth. Using a high grit (e.g. 600 grit) wet/dry sandpaper, wet sand the inside edge of the face mount (See Image 10A). Once the surface seems uniform and smooth, clean and dry the face mount. Lightly lubricate the -007 X-ring and install into the X-ring groove on the inside of the motor face mount. A pen cap, screw head or any other small object without sharp edges can be used to push the X-ring into place and ensure it sits flat in the groove. Once the X-ring is installed push the shaft of the motor into the X-ring so that the motor and adapter are flush to the inside wall of the motor face mount (See Image 10B). Use four #4-40 x 1/2" screws to secure the motor. **Again, only tighten screws hand-tight. Overtightening screws may strip the holes or break the 3D-printed motor face mount.**

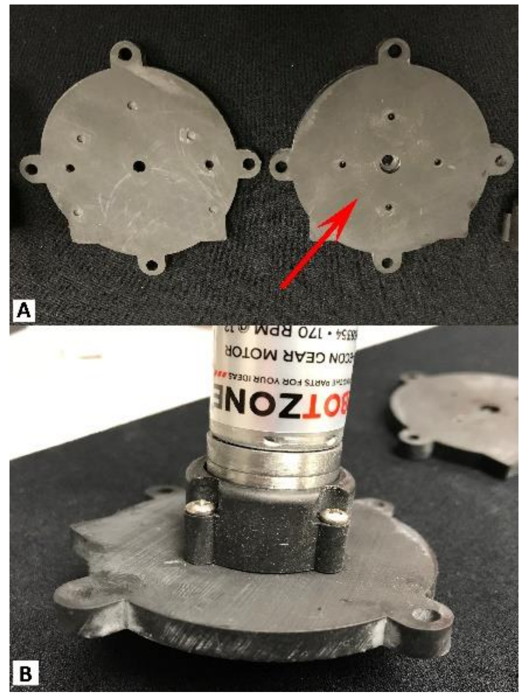
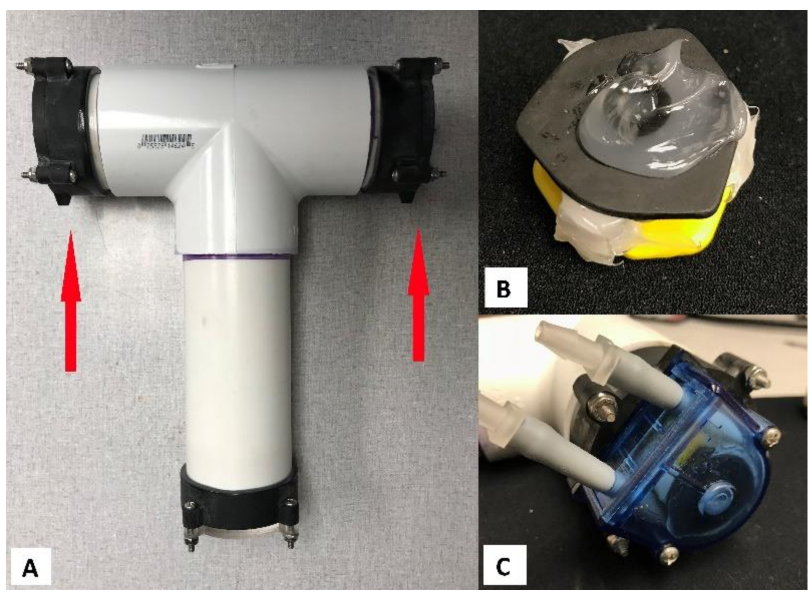


Image 10: (A) Red arrow indicating the X-ring groove. (B) Flush-mounted motor.

iv. Check for a watertight seal

To ensure the seal on the housing is watertight with the addition of the motor face mounts, install the motors into the two short sections of the PVC housing (See Image 11A). The motor wires will need to be led through the housing to open end of the long PVC section. A simple way to do this is to tape a light weight to the end of the wires so gravity will pull the wires through to where they will later connect to the main circuit board and power source. The O-rings on the endcaps should all be lightly lubricated and the motor face mount should only be tightened to hand-tight to create a watertight seal and prevent breakage. If the acrylic face plate was removed from the endcap on the long section of the housing it should be replaced and secured again as described in the previous water test. Using freshwater, hold the housing underwater



See Image 11: (A) Install the motor and face mounts to test seal. (B) Lubricate the carriage wheel and rollers. (C) Install the pump head on the motor face mount.

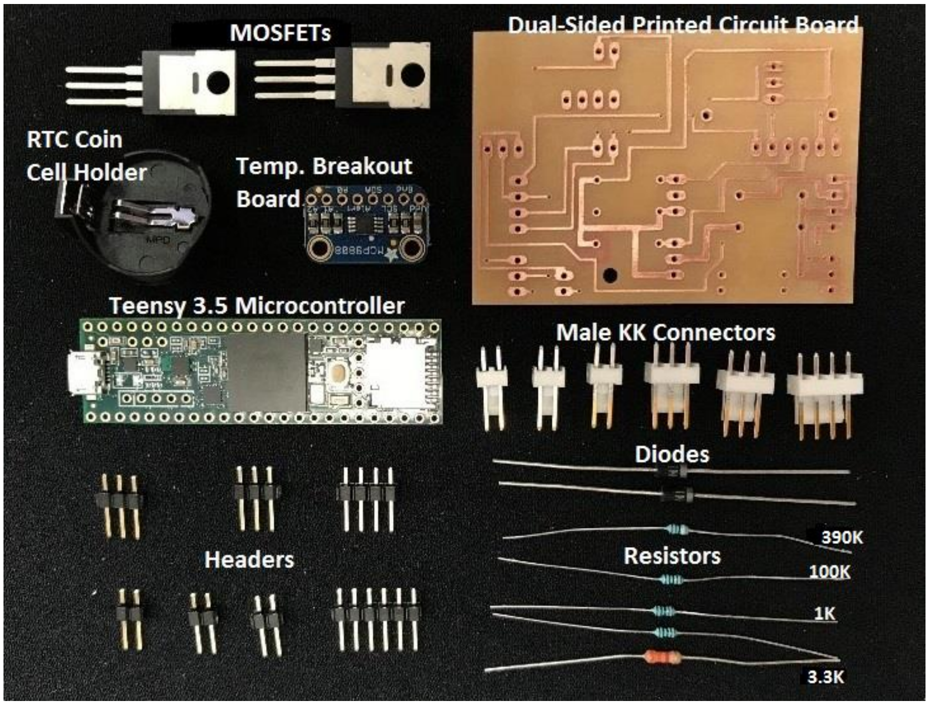
and look for any streams of bubbles. If any water enters the housing examine all O-rings and X-rings for dirtiness or signs of damage. If water does enter the housing and the motors become wet, remove the motors from the housing and allow to dry thoroughly before attaching to a power source to prevent motor damage.

v. Install the 3D printed pump head roller carriage

To install the 3D printed roller carriage for the pump heads, open the two unsealed pump heads and remove the existing carriage wheel. Carefully pull apart the carriage wheel and replace the shaft and roller mount with the 3D printed version. Using a synthetic lubricant, heavily lube the back of the carriage wheel and the rollers and then reinstall into the pump head (See Image 11B). To mount the pump head onto the motor line up the flat edges of the motor shaft and the pump head shaft housing and then install the shaft into the pump head. Make sure that the pump head lines up with its outline on the motor face mount (See Image 11C) and then secure in place with two #6-32 x 1 1/8" screws.

A step that will be useful when using the sampler later on is to label the housing next to the pumps "A" and "B" using a permanent marker or a waterproof label. This will help ensure that the pump is connected to the correct terminal and that the calibration settings for each pump are accurate. Similarly, labeling the KK connectors on the motor wires will also makes it easier to identify and connect the pumps properly when that time comes.

4. Building the circuit board:



To better understand the design and function of the SAS circuit board prior to construction, the schematic and diagram should be examined to trace the track of the circuit between components and compare it with the board's layout (See Appendix). Understanding the circuit is not crucial to construction of the SAS but it is helpful to perform advanced troubleshooting or alter the open-source design for other purposes.

i. Install vias

With a home milled circuit board vias must be installed and soldered into the board. If the circuit board is purchased online the vias are likely already part of the board. To install the vias, take one inch long sections of wire filament and place through each of the 1/64 inch via holes, then bend the filaments in half to keep in place (See Image 12). The wire filament can be taken from within any excess insulated wire (e.g. reed switch wire) by stripping short sections of insulated wire and clipping one inch long sections of the wire filaments from within. Once all via wires are in place solder them to the board being careful to heat both the wire and the copper of the circuit board to prevent cold solders that might break up conductivity. It's easiest to solder all the via wires on one side of the board before flipping it over to

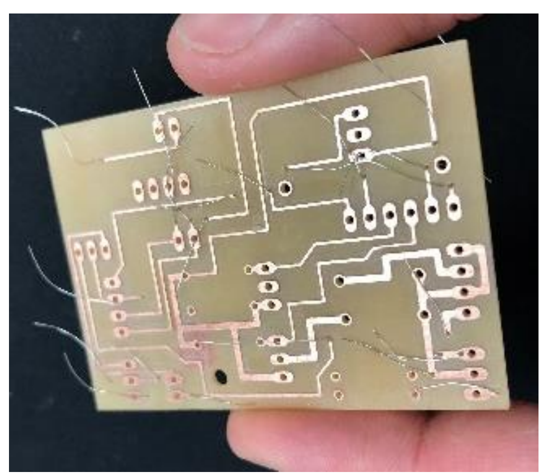


Image 12: The via wires installed prior to soldering.

solder the others. Use flush cutters remove any excess wire and solder from the vias.

ii. Install header pins

Insert the header pins for the Teensy 3.5, flip the board over, and solder the header pins to the board, being careful to keep the headers straight up and down so that the board fits (See Image 13). To double check, flip the board back over and place the Teensy on the pins to see if any are out of alignment. Remove Teensy for now, it will be the last piece to be soldered to the circuit board.

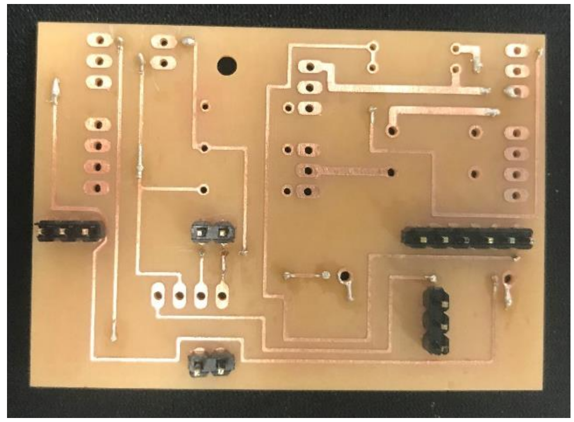


Image 13: Headers installed on the milled circuit board.

iii. Install resistors and diodes

Use a flat edge to bend the pins of the resistors and diodes at right angles. Install the resistors to the board and solder the top of each of the resistor pins. While direction of the resistors is unimportant, placement is, so be sure to double-check the location of each resistor before installing (See Image 14). Keep the resistors as low to the board as possible to save space. Install the diodes with the cathode (gray stripe) facing the outer edge of the board (toward the motor connection) and solder the pins onto the board. Direction with diodes is very important so be sure to double check that they are installed in the correct orientation (See Image 15). Flip the board over and solder the other side of the resistor and diode terminals and then use flush cutters to remove excess pins and solder.

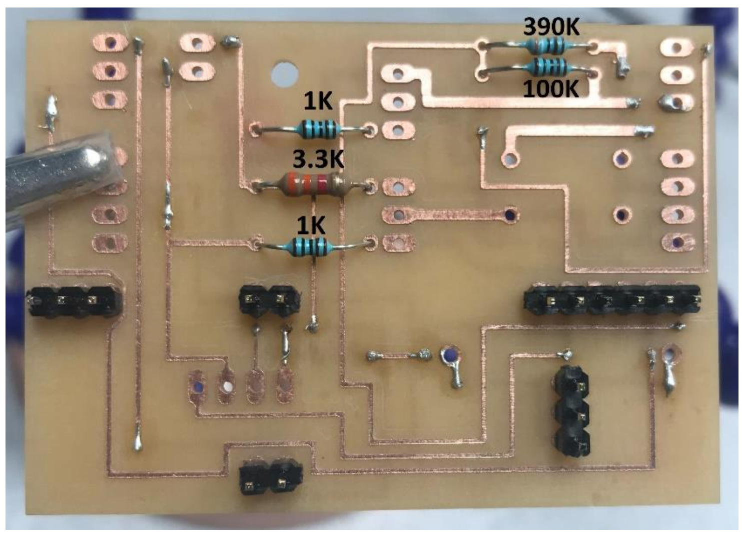


Image 14: Resistors installed into the circuit board.

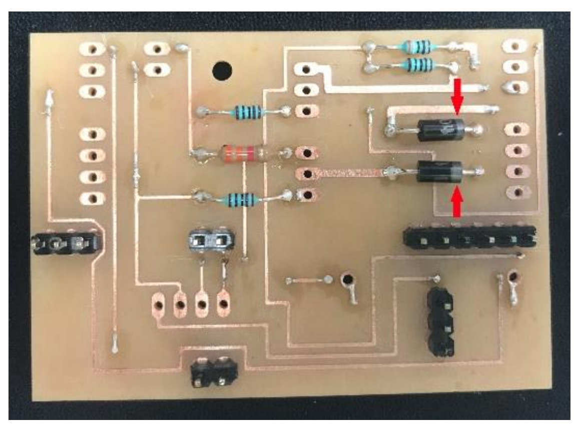


Image 15: Diodes installed in proper direction on circuit board.

iv. Install KK connectors

Install the male KK connectors onto the top of the circuit board (See Image 16) and flip the board over. Be sure KK connectors are installed straight up and down and then solder the pins to the board.

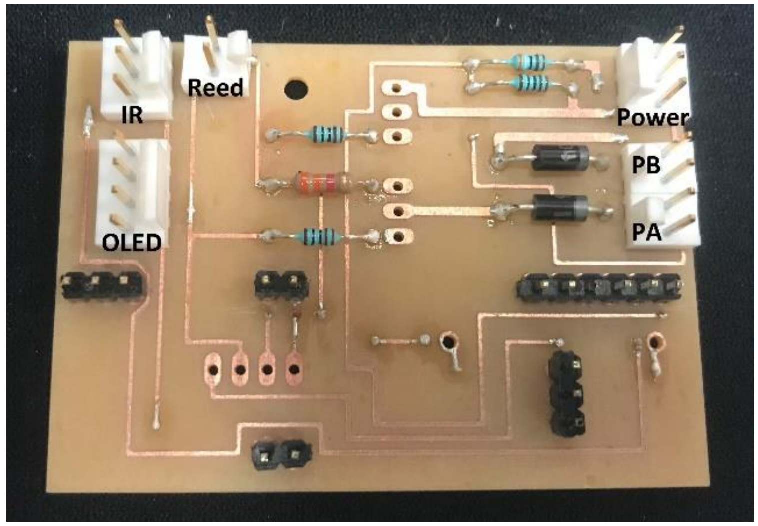


Image 16: The male KK connectors installed on the circuit board.

v. Install MOSFETs

Use a flat edge to bend the pins of the MOSFETs at a right angle. Install the MOSFETs into the top of the board and solder the pins in place (See Image 17). Flip the board over and solder the pins into place on this side as well, then, use flush cutters to remove excess pins and solder. As with all the board's components, be careful to heat both the board and the pins to ensure a good solder connection to avoid function and conductivity issues later on.

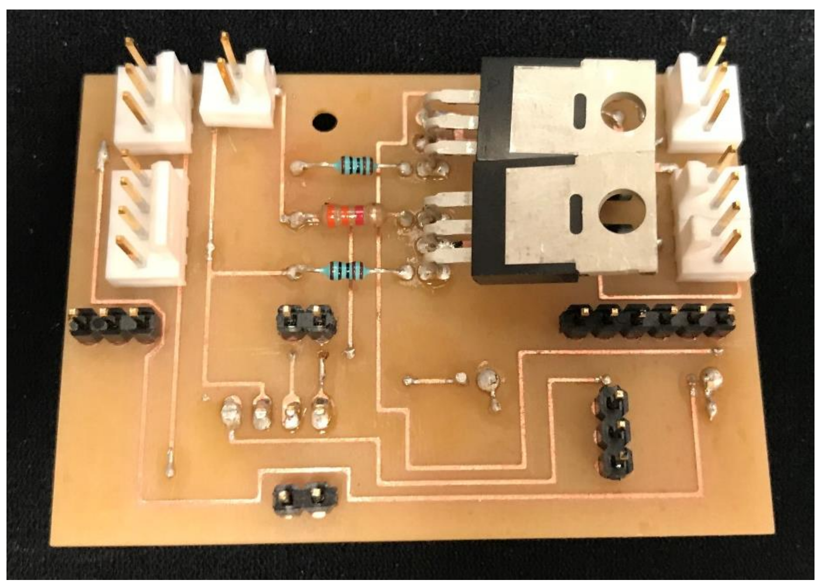


Image 17: MOSFETs installed on the circuit board.

vi. Install temperature breakout board

On the bottom of the board install the header pins for the temperature breakout board. Flip the board over and solder the header pins in place. Use flush cutters to remove excess pins and solder. Flip the board back over and solder the four indicated pins of the temperature breakout board to the header pins (See Image 18). Use the flush cutters to remove any excess pins and solder.

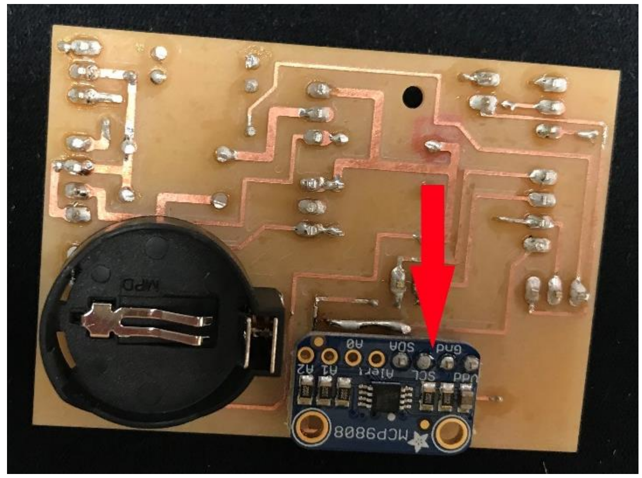


Image 18: The temperature breakout board properly mounted alongside the RTC coin cell holder.

vii. Install the coin cell battery holder

Install the RTC coin cell battery holder into the bottom of the board (See Image 18). Flip over the board and solder the battery holder pins in place. The short pins of the battery holder can make it difficult to get a good solder connection between the holder and the circuit board. To verify that the solder was done properly install a battery and use a voltmeter to verify current traveling between the two newly solder pins. The next step will cover these pins with the teensy, so it's important to check proper installation before moving on.

viii. Install the Teensy

Place the Teensy microcontroller in position on the pins on the top of the board and carefully solder the pins (See Image 19). Use caution not to touch any of the other components of the Teensy which might damage the function of the board.

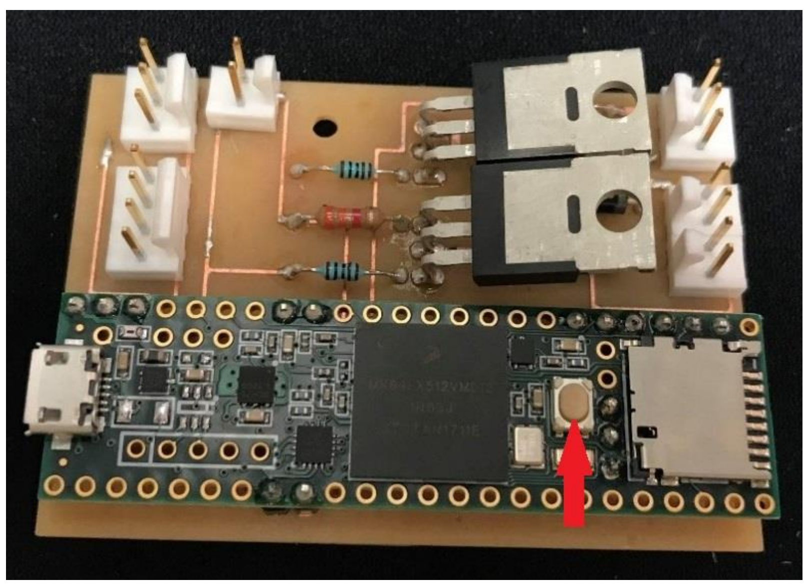


Image 19: The completed circuit board for the sampler. The red arrow indicates the reboot pushbutton.

ix. Prepare and install the microSD card

The Teensy 3.5 microcontroller can log data on a microSD card inserted in the Teensy's microSD slot. This is where the general settings for the sampler will be stored and where all the data will be recorded, including temperature, time and date of pump alarms firing, and codes for sampler troubleshooting. For the microSD card to communicate with the Teensy properly, two text files need to be uploaded to the card prior to using it. Using an adapter or a microSD card reader, connect the microSD card to a computer and open up the microSD card and a text editor (e.g. Notepad or TextEdit). The two text files that need to be saved to the microSD card should be titled "dataLog.txt" and "sampleParam.txt". The dataLog.txt file will be blank and only needs to be named and saved to the card. On the sampleParam.txt file add and save the following three lines of code to input initial settings for your water sampler:

1,10,10,100,1
1,0,1,1,18
1,15,1,1,18

Once the text files have been added to the microSD card it can be inserted into the slot on the Teensy.

x. Install the sampler code to the Teensy 3.5

Follow the instructions on the Teensy website (https://www.pjrc.com/teensy/td_download.html) to setup both the Arduino and Teensy software on your computer. Be sure to download a version of the Arduino software that is compatible with the Teensy software (e.g. Arduino 1.8.7). Download the programming code for the SAS from the NOAA website's build page (http://www.coral.noaa.gov/accrete/SAS) and place it into a new folder within the Arduino libraries folder, found in the Arduino folder in the Documents folder. The folder the code is placed in needs to match the name of the code for it to work with the Arduino software. For example, if the code file is named "brainV2B.ino" name the folder "brainV2B".

Next, the necessary Arduino libraries need to be added to allow the SAS code to function properly. Run the Arduino software and select the Sketch menu. Select "Include Library" and then "Manage Libraries" and the Library manager window will popup. Search for "Adafruit_MCP9808 library" in the search bar and install the most recent version of the library. The installation process will place the library in the same Documents folder as the SAS code. Next search for the library called "SdFat" and install the most recent version. The last library required for the SAS code should already be installed. Open up the "hardware" folder inside the Arduino folder and then go into the "teensy" folder, open up the "avr" folder, and then the "libraries" folder. Look for the "Adafruit_SSD1306" folder. On a Mac the Arduino icon can be selected with a right-click to bring up the drop menu, then select "Show Package Contents", the "Contents" folder, "Java" folder, "hardware" folder, from which point the process is the same as described above.

Once the Adafruit_SSD1306 folder is found open the Adafruit_SSD1306.h file with a text editor (e.g. Notepad or TextEdit) and scroll down to the following line:

```
   -----------------------------------------*/
// #define SSD1306_128_64
   #define SSD1306_128_32
// #define SSD1306_96_16
/*=========================*/
```

The default setup will be the 128 x 32 bit screen resolution. The SAS resolution needs to be 128 x 64 bit. To fix this, uncomment the 128 x 64 bit screen resolution by deleting the two forward slashes in front of SSD1306_128_64 and add two forward slashes in front of SSD1306_128_32 so it looks like this:

```
-----------------------------------------*/
   #define SSD1306_128_64
//  #define SSD1306_128_32
//  #define SSD1306_96_16
/*=========================*/
```

Once finished, save and close the text file. The last step in preparing the code for use is to edit the code for the SAS's sleep mode. This code minimizes the amount of current draw while sleeping so the SAS can be deployed for long periods of time. The following edits allows sampling alarms to be set in advance for a larger range of time (years rather than weeks). In the same Libraries folder as Adafruit_SSD1306, open the folder labeled Snooze and then the folder labeled Utility. Use a text editor to edit and save these two files: SnoozeAlarm.h and SnoozeAlarm.cpp. In SnoozeAlarm.h find the line near the bottom of the document that looks like:

void setRtcTimer(uint8_t hours, uint8_t minutes, uint8_t seconds);

Change that line to:

void setRtcTimer(uint32_t hours, uint32_t minutes, uint32_t seconds);

In SnoozeAlarm.cpp find the line near the top of the document that looks like:

void SnoozeAlarm::setRtcTimer(uint8_t hours, uint8_t minutes, uint8_t seconds) {

Change that line to:

void SnoozeAlarm::setRtcTimer(uint32_t hours, uint32_t minutes, uint32_t seconds) {

The SAS code is now ready to be uploaded onto the Teensy microcontroller. Open the Arduino software (also called the Arduino Integrated Development Environment (IDE) and select the Tools menu. Select "Board:" and choose Teensy 3.5; this step is necessary the first time you open Arduino so the program knows which type of microcontroller is being programmed. From the File menu select "Open…" and navigate to the Arduino library folder, where the SAS code was saved, and open the code file. When the code has opened on the Arduino IDE click the verify button to compile the code for uploading to the Teensy. Once the code is compiled the Teensy program (Teensyduino) will automatically open. Connect the Teensy to the computer using the micro USB port. Under the Arduino Tools menu go to "Port" and choose the serial port that the Teensy is plugged into. Press the tan reboot button next to the microSD card slot on the Teensy (See Image 19) and then click on the upload button on the Teensy program to upload the SAS code to the Teensy. Once the upload is complete the circuit board is now ready and can be connected to the sensors and the screen to verify its function.

If this is the first time the Teensy has been programmed, the Teensy serial port will not be available under the Port menu. Carry out the other steps above, and then return to the Port menu, the Teensy serial port will now be available, select the port and repeat the upload to make sure the code is uploaded properly.

5. Setting up the internal armature:

i. Prepare the parts

Use a rough sandpaper to sand all surface of the 3D printed internal frame to smooth out surfaces and remove any resin tabs. Make sure that the face of the frame, where the OLED, IR sensor, and reed switch holes are, is sanded until smooth and uniform, then use a high grit wet/dry sandpaper to wet sand the face of the frame further. Clean and dry the frame.

ii. Attach frame to acrylic face plate

Remove only the center circle from the plastic layer on the laser cut acrylic face plate. Be sure to leave the small squares of plastic attached to prevent the adhesive from smudging across the screen and sensor areas (See Image 20). Coat the face of the 3d-printed frame with clear acrylic solvent cement and press the frame face onto the inner circle of the acrylic face plate, being careful to line up the frame face with the boundaries of the clear acrylic circle. Weight the frame in place to create pressure on the frame/acrylic join. Let the adhesive cure for 18 to 24 hours for a full cure and then remove the plastic layer from the outer edge of the acrylic face plate and within the spaces for the reed switch, OLED, and IR sensor (tweezers will likely be needed to remove these small pieces).

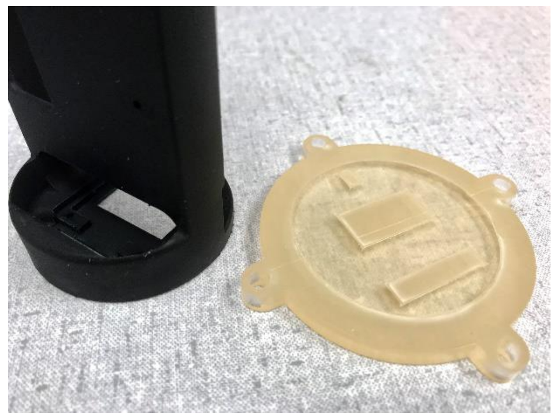


Image 20: Plastic scored circle removed from acrylic face plate to serve as guide for attaching the face of the frame to the face plate.

****If the frame is not well lined up with the face plate during gluing the armature may not be able to be inserted into the housing fully. ****

iii. Insert the reed switch, OLED, and IR sensor

Insert the Reed switch into the space on the face of the frame (See Image 21). Attach the reed switch using two #6-32 1/8 inch long screws. **All components installed into the 3D printed frame should be no more than finger-tight to avoid damaging threaded holes or the frame.** Cut the wires of the Reed switch to be about four inches long and remove the last 1/8 inch of the insulated sleeve. Attach KK crimp terminals onto the ends of the two wires and plug the wires into a 2-hole female KK connector (the order does not matter).

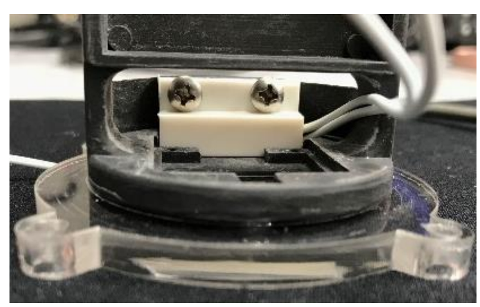


Image 21: Reed switch installed into armature.

Insert the OLED into the space in the face of the frame, taking care to orient the screen properly (See Image 22) and attach using two #2-56 x 1/8 inch long screws at opposite corners. **The OLED has a glass screen which is easily cracked if tightened too much**, so only screw in the screen until there is some resistance, less than hand-tight.

Use a flat edge to bend the pins of the IR sensor at a right angle to the flat back of the sensor. Clip the pins so they're ¼ inch long. Lightly coat the outside edges of the sensor in two-part epoxy and place into the IR sensor hole in the face of the frame (See Image 22). A small piece of tape can hold the sensor in place while the resin cures for 18-24 hours.

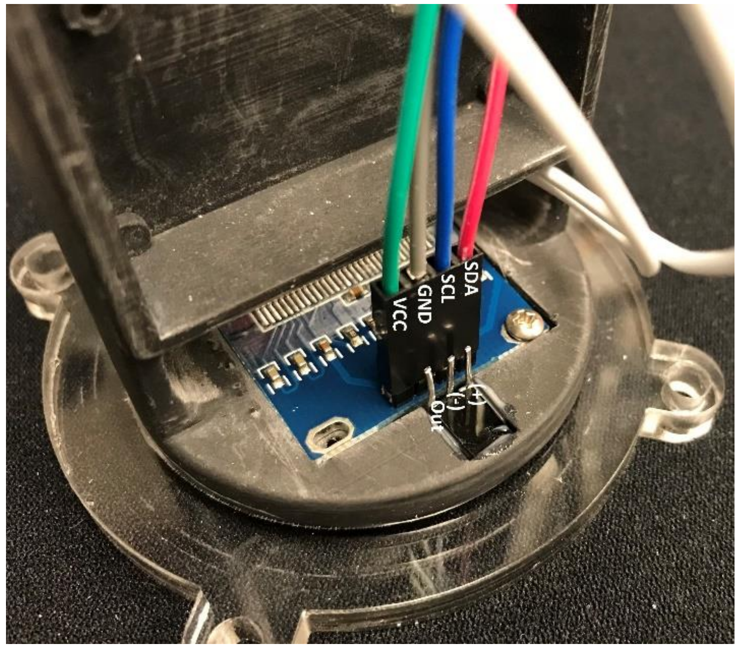


Image 22: OLED and IR sensor installed into the armature.

iv. Installing the power connection:

Remove 1/8 inch of the insulated sleeve on a four inch length of red 26 AWG wire. Solder the end of the wire onto the free positive terminal on the 9 volt dual strap (See Image 23) and add ½ inch of heat shrink tubing onto the solder to strengthen the connection. Route the new red wire through the upper left hand hole and push the dual strap into position in the battery compartment of the frame. The original black and red wire should be led through their respective channels in the frame to the outside of the battery compartment. The dual strap should be secured using two #2-56 x ½ inch long screws and two #2-56 nuts. Strip the last 1/8 inch of the insulated sleeve of each of the 3 wires and attach a KK crimp terminal to the end. Install the wire terminals into a 3-hole female KK connector with the new red wire on the outside edge, the original red wire in the center, and the original black wire on the inside (See Image 24).

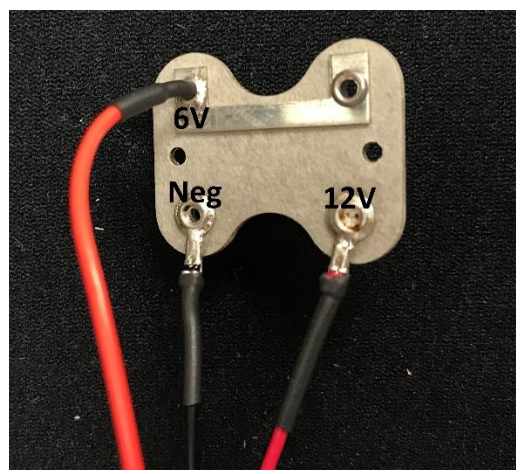


Image 23: 26AWG wire soldered onto 9-volt dual strap.

v. Setting up connections for the OLED & IR sensor

To make connections for the OLED and the IR Sensor take the seven different colored 26 AWG wires and strip 1/8 inch off each end of the wires. On one end of each wire attach a DuPont female crimp pin, on the other end of each wire install a KK crimp terminal. Plug four of the wired KK crimp terminals into a 4-hole female KK connector and plug the other ends (with the DuPont pins), in the same order, to a 4-hole DuPont connector housing (See Image 25). Plug the KK crimp terminals of the other three wires into a 3-hole female KK connector and the three DuPont pins in the same order to a 3-hole DuPont connector housing.

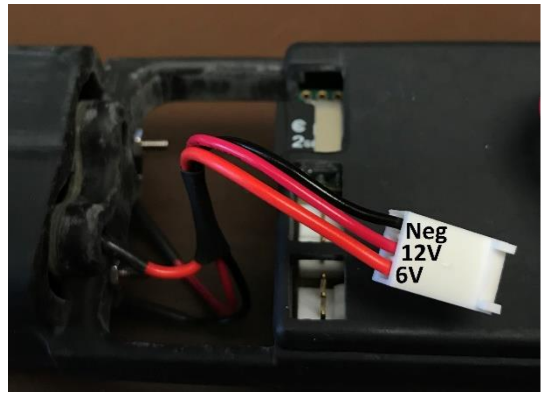


Image 24: Wiring for power source connector.

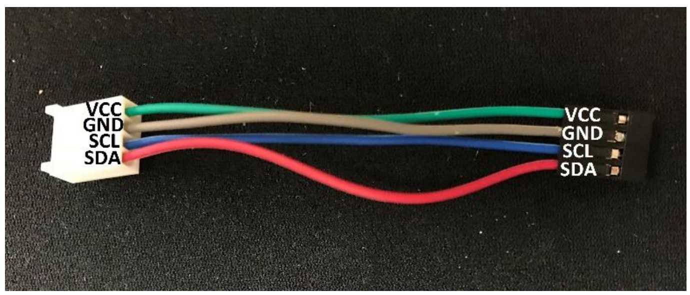


Image 25: The wiring for the OLED connection.

vi. Putting the armature together:

Place the circuit board into the armature with the battery and temperature breakout board down. The coin cell holder and the temperature breakout board will stick out of the frame slightly through their customized openings. Put on the circuit board cover and secure in place with the #2-56 x 3/4 screw. The screw head will be flush with the lid and the tip of the screw will just start to exit the back of the armature. Attach the KK connectors to the board for the Reed switch, IR sensor, and OLED (See Image 26). Reverse the wire order for the OLED by twisting the wires and then plug the 4-hole DuPont connector onto the OLED pins. Plug the 3-hole DuPont connector onto the IR sensor pins in the same order. Insert the microSD card. Attach the KK connector for the battery connection.

****Note that attaching the power before the OLED, IR sensor, and Reed switch might interfere with the function of those components, so always attach the power last.****

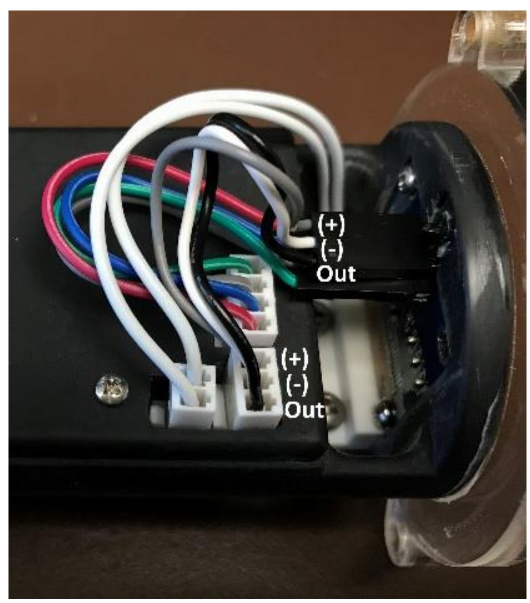


Image 26: OLED, IR sensor, and Reed switch connections to circuit board.

Fill two of the 4AA battery packs with fully charged batteries and insert battery packs into the sampler until they snap into the 9-volt dual battery strap. The battery pack below the power connection to the circuit board should always be plugged in first (See Image 27A) followed by the second battery pack. The sampler will turn on automatically, ready for programming using the IR remote. Looping a rubber band under the battery packs and hooking it on the power connection hardware will help ensure the batteries don't disconnect from the 9-volt connector if the internal armature gets jolted. Attach the two motor KK connectors to the circuit board. The connection for Pump A is on the left and Pump B on the right (See Image 27B). Slide the complete armature into the housing and secure with four hand-tightened #6-32 lock nuts.

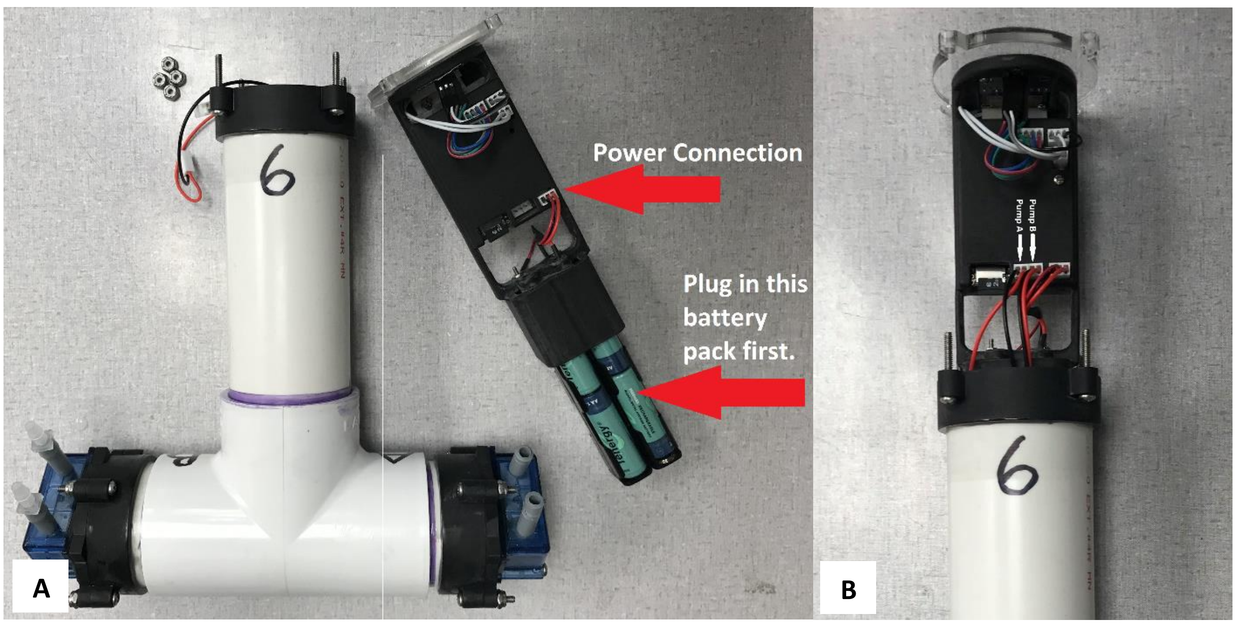


Image 27: (A) The finished sampler housing and internal armature put together. The red arrow indicates which battery pack to attach first. (B) Sliding the internal armature into the housing, and the white arrows indicate where the pump motors connect to the circuit board.

6. Making the neoprene sample bag covers:

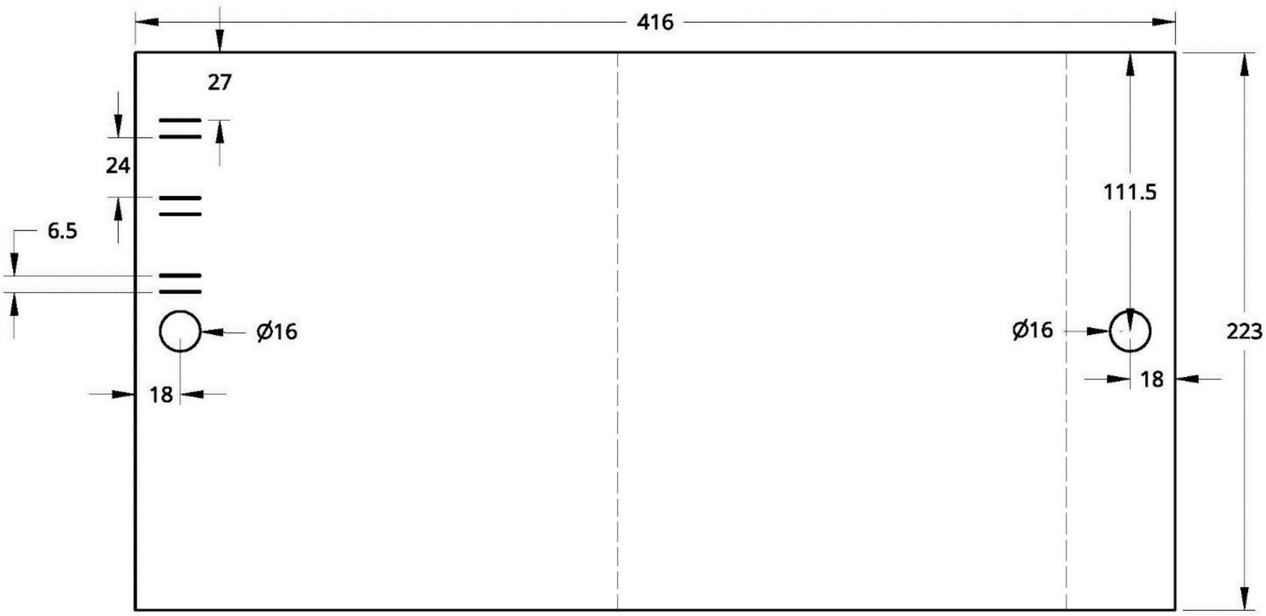


Image 28: A diagram of the dimensions in mm, design, and folding pattern for making a neoprene protective bag for the SAS.

Cut the neoprene according to the dimensions in Image 28 (note that the units are millimeters), then fold the neoprene on the dotted lines. Next install grommets in the two top corners of the bag (See Image 29). Each sampler requires two of the neoprene protective bags. The Tedlar sample bag should be placed in the folded contours of the protective bag with as few creases as possible. The valve of the Tedlar bag comes out of both holes in the neoprene to secure the neoprene flap. Attach a six inch length of Tygon tubing from the outflow of the pump to the stem of the Tedlar bag valve using the neoprene slits to secure the tubing and minimize valve movement during deployment (See Image 30).

Image 29: The finished neoprene protective bag.

Image 30: The final sampler setup with installed sample bags.

Finally, using stainless steel clips connect the grommets on the neoprene bags to the top and bottom of the housing (See Image 30) using zip ties to attach the clips to the sampler housing.

For instructions on programming and deploying the sampler please refer to the SAS User Manual, available online at (http://www.coral.noaa.gov/accrete/SAS).

As the SAS continues to be used and further developed please send any feedback or questions about the sampler and its design or function, or the user and build manuals, to Nathan.formel@noaa.gov

APPENDIX

On the top is the schematic for the SAS circuit with labels to match up the components on the board and in the diagram with the circuit pathways. On the bottom is the diagram showing the circuit board's layout with the paths depicted as either red or blue depending on the side of the board that they're located on. Understanding the way the circuit is designed and functions allows for easier troubleshooting and modification of the SAS.